

## **WASTEWATER TREATMENT WITH ALKANES**

### **CROSS REFERENCE TO RELATED APPLICATION**

**[0001]** This application is a divisional of U.S. Patent Application Serial No. 09/924,791 filed August 8, 2001, which claims the benefit of U.S. Provisional Patent Application Serial No. 60/291,165 filed May 15, 2001, and is a continuation-in-part of U.S. Application Serial No. 09/729,039 filed December 4, 2000, now U.S. Patent No. 6,488,850 issued December 3, 2002, which is a continuation-in-part of U.S. Application Serial No. 09/275,320 filed March 24, 1999, now U.S. Patent No. 6,245,235 issued June 12, 2001, which is a continuation-in-part of U.S. Application Serial No. 08/767,750 filed December 17, 1996, now U.S. Patent No. 5,888,396 issued March 30, 1999. All of the foregoing applications and patents are incorporated herein by reference.

### **FIELD OF THE INVENTION**

**[0002]** The present invention relates to the treatment of wastewater, and more particularly relates to the use of alkanes to aerobically and/or anaerobically treat municipal, agricultural and industrial wastewater.

### **BACKGROUND INFORMATION**

**[0003]** Liquid wastes are produced by most human activities including domestic sewage, agricultural processes and industrial operations. For example, according to the U.S. Department of Commerce, industrial water users discharge approximately 285 billion gallons of wastewater daily.

**[0004]** Some types of conventional wastewater treatment processes are microbiologically mediated. Municipal, agricultural and industrial wastewater is often treated aerobically, thereby converting pollutants into environmentally acceptable analogues. The addition of micro-bubbles of oxygen has been demonstrated to be an effective enhancement of the aerobic treatment of wastewater to lower biological oxygen demand (BOD), total dissolved solids (TDS) and total organic carbon (TOC).

**[0005]** Anaerobic wastewater treatment methods have also been used. For example, the addition of hydrogen has been found to enhance anaerobic processes, and to reduce

unsaturated organic liquids and sludges. Anaerobic digestion is one of the oldest processes used for the stabilization of sludges. It involves the decomposition of organic matter and inorganic matter in the absence of molecular oxygen. During conventional anaerobic digestion, the organic matter in mixtures of primary settled and biological sludges is converted biologically, under anaerobic conditions, to produce methane ( $\text{CH}_4$ ) and carbon dioxide ( $\text{CO}_2$ ). During conventional anaerobic digestion, a consortium of organisms converts organic sludges and wastes. One group hydrolyzes organic polymers and lipids. A second group of anaerobic bacteria ferments the breakdown products to simple organic acids. A third group of microorganisms converts the hydrogen and acetic acid to methane gas and carbon dioxide.

[0006] Gas-liquid mixing systems are used in various processes and methods employed in the wastewater industries. Many types of mechanical devices and mixers have been developed to improve wastewater treatment by enhancing gas-liquid mixing. By enhancing gas-liquid mixing, wastewater aerobic treatment processes are improved through increased oxygen (aerobic) and hydrogen (anaerobic) dissolution and residence time.

[0007] U.S. Patent Nos. 5,916,491 and 5,925,290, which are incorporated herein by reference, disclose apparatus and methods for mixing gas and liquid through vortex or venturi devices. The mixers are particularly suited for mixing oxygen-containing gases into industrial and municipal wastewater. Other types of gas-liquid mixers are also disclosed in U.S. Patent Nos. 3,969,446, 4,328,175, 4,454,077, Re. 32,562, 4,645,603, 4,695,378, 4,956,080, 5,061,406, 5,073,309, 5,085,809, 5,314,076 and 5,494,576, which are incorporated herein by reference.

[0008] The bioremediation of various pollutants such as chlorinated solvents and other types of pollutants using butane-utilizing bacteria is disclosed in U.S. Patent Nos. 5,888,396, 6,051,130, 6,110,372, 6,156,203 and 6,210,579, which are incorporated herein by reference.

### SUMMARY OF THE INVENTION

[0009] In accordance with the present invention, alkanes, e.g., methane, ethane, propane and butane, can be used to effectively degrade pollutants and other materials

typically found in wastewater such as chemical, industrial and municipal effluents. In a preferred embodiment, butane, having the highest solubility of the alkanes, can be used to control BOD, TOC and TDS, as well as pollutants typically found in wastewater through enhanced growth of aerobic and/or anaerobic bacteria, and possibly other microorganisms that oxidize or reduce dissolved organic matter and sludge effluents, thereby significantly decreasing the BOD of a wastestream.

[0010] Alkanes, preferably butane, may be used under aerobic and/or anaerobic conditions to enhance wastewater treatment processes during primary, secondary or tertiary treatment. Butane is highly soluble and ideally suited to serve as a microbial growth substrate, thereby significantly increasing the heterogeneous microbial community and total heterotrophic microbial population found in wastewater. This enhanced microbial population may rapidly absorb and mineralize the dissolved organic nutrients in the wastestream. To accelerate the dissolved organic nutrient reductions, the butane may be pulsed in the wastestream to create feeding frenzy/starvation cycles. After the initial growth phase, the organic matter available in the wastewater effluent may be rapidly decreased thereby reducing the BOD, TOC and TDS.

[0011] An aspect of the present invention is to provide an apparatus for treating wastewater comprising means for introducing at least one alkane into the wastewater.

[0012] Another aspect of the invention is to provide an apparatus for treating wastewater comprising a wastewater containment vessel, and at least one alkane injector in flow communication with the wastewater containment vessel.

[0013] These and other aspects of the present invention will be more apparent from the following description.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Fig. 1 is a partially schematic side view of an alkane aerobic digester in accordance with an embodiment of the present invention.

[0015] Fig. 2 is a top view of the alkane aerobic digester of Fig. 1.

[0016] Fig. 3 is a partially schematic side view of an alkane anaerobic digester in accordance with an embodiment of the present invention.

[0017] Fig. 4 is a top view of the alkane anaerobic digester of Fig. 3.

[0018] Fig. 5 is a partially schematic side view of a gas-liquid mixer including an alkane injection system in accordance with an embodiment of the present invention.

[0019] Fig. 6 is a partially schematic side view of a gas-liquid mixer including an alkane injection system in accordance with another embodiment of the present invention.

[0020] Fig. 7 is a top view of the gas-liquid mixer of Fig. 6.

[0021] Figs. 8a and 8b are schematic diagrams illustrating a butane-enhanced wastewater treatment process in accordance with embodiments of the present invention.

[0022] Fig. 9 is a schematic diagram illustrating a butane-enhanced wastewater treatment process in accordance with another embodiment of the present invention.

[0023] Fig. 10 is a partially schematic side view of a bioreactor used to treat municipal wastewater sludge with butane in accordance with an embodiment of the present invention.

#### DETAILED DESCRIPTION

[0024] In accordance with the present invention, aerobic and/or anaerobic digestion with alkane-utilizing bacteria is used to treat wastewater materials, such as organic sludges produced from various treatment processes. In accordance with a preferred embodiment of the present invention, butane, which has relatively high solubility, rapidly dissolves in wastewater, thereby significantly increasing heterogeneous microbial communities and heterotrophic microbial populations. Butane is a low molecular weight organic compound ideally suited to serve as a microbial food substrate under aerobic and/or anaerobic conditions. Butane is non-toxic and may be added, for example, as an amendment in a primary settling tank, aeration tank or secondary settling tank.

[0025] In accordance with an embodiment of the present invention, a butane substrate may be added to the wastewater to be treated. A preferred embodiment of the present invention relates to the treatment of wastewater BOD, TDS and sludge. For example, a butane substrate may be injected into the wastewater in a large treatment vessel equipped with oxygen injectors and turbulent mixing devices. The butane substrate may be provided in any desired form, such as a liquid or gas injected into the wastewater, or within a capsule that dissolves in the wastewater.

**[0026]** As used herein, the term “butane substrate” includes liquids and gases in which butane is present in sufficient amounts to stimulate growth of butane-utilizing bacteria. Butane is preferably the most prevalent compound of the butane substrate on a weight percent basis, and typically comprises at least about 10 weight percent of the butane substrate. The other constituents of the butane substrate may include any suitable compounds, including inert gases and/or other alkanes such as methane, ethane and propane. The butane substrate preferably comprises at least about 50 weight percent butane. More preferably, the butane substrate comprises at least about 90 weight percent butane. In a particular embodiment, the butane substrate comprises at least about 99 weight percent n-butane. The butane may contain straight (n-butane) and/or branched chain compounds.

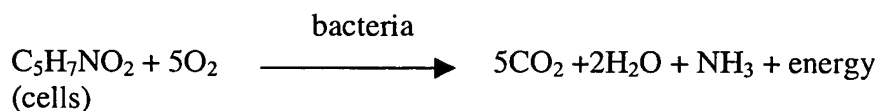
**[0027]** Oxygen may be introduced into the wastewater during at least a portion of the treatment time. As used herein, the term “oxygen-containing gas” means gases which comprise oxygen, including pure oxygen as well as mixtures of oxygen with other gases. For example, the oxygen-containing gas may comprise air, pure oxygen, or oxygen blended with inert gases such as helium, argon, nitrogen, carbon monoxide or the like.

**[0028]** Although the use of a butane substrate is primarily described herein, it is to be understood that other alkanes, i.e., methane, ethane and/or propane, may be used in addition to, or in place of, butane. For example, natural gas may be used as a food source. Furthermore, alternative food sources may be used in addition to, or in place of, the alkanes. Examples of alternate food sources include agars, simple and complex sugars, carbohydrates, carbon sources, milk products, egg albumin, egg products, blood serums, urea, urea broth, beet molasses, glucose, xylose and glucose, xylose, mannose, lactate, mannitol, yeast extract, sorbitol, wheat bran, straw, molasses, cereals, corn, potato starch, corn cob, fish meal, grain, gelatin, corn steep liquor, corn meal, nutrient gelatin, rice bran, casein hydrolysate, ethanol, agricultural residues, peat moss hydrolysate, lactose, sugar-cane syrup, synthetic ethanol, gasoline, petroleum distillates, aliphatic and aromatic hydrocarbons, non-petroleum compounds, fructose, fatty acids, proteins, cellulose, engineered biological fuel components, nitrates/nitrites/ammonia, maltose, sucrose, starch, acetate, glycerol, soluble starch, amino acids, casamino acids, meat extracts, organic acids, barley, barley malt, blood meal, cane (black strap) molasses,

cerelose, CFS concentrate, corn gluten meal, cotton seed meal, dried distillers' solubles, edamine, enzose, fermamin, fish solubles, fish meal, linseed meal, meat and bone meal, NZ-Amine B, oat flour, peanut meal and hulls, pharmamedia, rice flour, soybean meal, wheat flour, whey powder, brewers' yeast, yeast hydrolysate, yeast tortula, arabinose, fumarate, pyruvate, succinate, phosphate, galactose, glycol, crotonate, glutamate, arginine, ribose, methanol, propanol, fuel oils, all volatile petroleum hydrocarbons (VPH) and all extractable petroleum hydrocarbons (EPH) including the C<sub>5</sub>-C<sub>8</sub> aliphatic range, C<sub>9</sub>-C<sub>12</sub> aliphatic range, C<sub>9</sub>-C<sub>10</sub> aromatic range, C<sub>11</sub>-C<sub>22</sub> aromatic range, C<sub>9</sub>-C<sub>18</sub> aliphatic range, C<sub>19</sub>-C<sub>36</sub> aliphatic range, C<sub>36</sub> and higher aliphatic range, benzene, toluene, ethylbenzene, xylenes, naphthalene, polynuclear (1, 2, 3 rings and higher) hydrocarbons (PAHs), butyrate, butylaldehyde, butanol, 1-butanol, 2-butanol, pentane, nonane, styrene, octane, n-octane, organic compounds, alcohols, hexadecanol, ethylene glycol, microbial metabolites, carboxylic acids, acids, such as formic, acetic, propionic, oxalic, acrylic, methacrylic, mineral spirits, mineral oils, petroleum jellies, aldehydes, mushroom extracts, mushrooms, aliphatic amines, aromatic amines, ethers, aliphatic and aromatic esters, glycol ethers, ketones, grain dust, phenols, cheese whey, gas oils, cellulose-pulping, carbon dioxide, gas and oil, carob bean extract, waste starch, fermentation products, endogenous oxidized cell tissue, high molecular mass compounds, cell protoplasm, dead microbial cells, wood, wood chips, sawdust, coal and coal dust.

**[0029]** In accordance with a preferred embodiment, butane availability results in the selection of robust and diverse microbial populations. These enhanced microbial populations may rapidly absorb and mineralize the dissolved organic nutrients in the wastestream. After this initial growth phase, the organic matter available in the wastewater effluent will be rapidly decreased thereby reducing the BOD, TDS and sludge components.

**[0030]** Typically, during aerobic digestion, in a process known as endogenous respiration, as an available food substrate is depleted, the microorganisms begin to consume their own protoplasm to obtain energy for cell maintenance reactions as shown by the following equation:



[0031] For example, if activated or trickling filter sludge is mixed with primary sludge and the combination is to be aerobically digested, there will be both direct oxidation of the organic matter in the primary sludge and endogenous oxidation of the cell tissue as the readily available organic matter is depleted. One consequence of butane availability in a wastestream, e.g., by cycling or pulsing, is to accelerate oxidation of the organic matter by reducing endogenous respiration. Another benefit of butane availability is the direct result of the increase in cell densities and the microbiological diversity resulting under butane tension. This increased microbiological community will further enhance organic matter digestion.

[0032] The butane aerobic digesters may be used, for example, to treat waste-activated or trickling-filter sludge, mixtures of waste-activated or trickling-filter sludge and primary sludge, and/or waste sludge from activated-sludge treatment plants designed without primary settling.

[0033] In addition to dissolved solids removal, the butane/oxygen process may be used to accelerate sludge decomposition and reduction. High oxygen concentrations may be maintained for microbial proliferation and to reduce bulking of the sewage sludge. For example, by retrofitting existing conventional wastewater treatment tanks, a butane aerobic digester may be added into the process flow during any stage of the overall treatment process. Settled and dissolved biomass may be continuously recycled to maximize the rate of aerobic digestion. Since many wastewater facilities include aeration tanks equipped with mixers and air and/or oxygen injection diffusers, the system retrofit may simply include the addition of butane injectors such as ports and/or diffusers. Likewise, conventional anaerobic digesters may be converted to butane anaerobic digesters through the addition of butane injectors.

[0034] In accordance with an embodiment of the present invention, alkane-utilizing bacteria may be used to anaerobically treat wastewater materials. For example, butane may serve as an electron donor to degrade recalcitrant compounds under anaerobic conditions through reductive dechlorination processes. Under anaerobic conditions, butane availability may increase enzyme-mediated biotransformations, such that higher-molecular-mass compounds are converted into compounds suitable for use as a source of energy and cell

carbon. Butane may thus serve as an electron donor to degrade recalcitrant compounds under anaerobic conditions.

[0035] Fig. 1 is a partially schematic side view of an aerobic butane digester 10 in accordance with an embodiment of the present invention. Fig. 2 is a plan view of the aerobic butane digester 10 shown in Fig. 1. The digester 10 includes a vessel 12 which contains wastewater 14. A wastewater feed line 16 feeds the wastewater into the vessel 12. A solids removal line 18 permits the removal of solids and other materials from the vessel 12. An impeller 19 is mounted in the vessel 12. An alkane injection line 20 is connected to diffusers 22 inside the vessel 12. An oxygen-containing gas injection line 30 is connected to diffusers 32 inside the vessel 12. As shown most clearly in Fig. 1, during operation of the aerobic butane digester 10, the impeller 19 is rotated in order to circulate the wastewater 14 within the vessel 12. The alkane and oxygen-containing gas are introduced into the wastewater 14 through the diffusers 22 and 32, respectively. The alkane is typically introduced in the wastewater 14 in pulses or intervals. The oxygen-containing gas may be injected into the wastewater 14 continuously or intermittently.

[0036] Figs. 3 and 4 are partially schematic side and plan views, respectively, of an anaerobic butane digester 34 in accordance with an embodiment of the present invention. The anaerobic butane digester 34 shown in Figs. 3 and 4 is similar to the digester shown in Figs. 1 and 2, except the oxygen-containing gas injection lines are replaced with additional alkane injection lines 20. The anaerobic butane digester 34 also includes a vent line 36. During operation of the anaerobic butane digester 34, the impeller 19 likewise rotates to circulate the wastewater 14, while the alkane is introduced into the wastewater 14 with the diffusers 22. The alkane may be introduced into the wastewater 14 continuously intermittently.

[0037] In addition to the embodiments shown in Figs. 1-4, conventional gas-liquid mixers may be adapted or modified to allow for the injection of butane or other alkanes into the treatment zone. For example, gas-liquid mixers as disclosed in U.S. Patent Nos. 5,916,491 and 5,925,290 may be modified to introduce butane at any desired location(s) in the liquid stream, for example, inside the draft tube of the mixers.

[0038] Fig. 5 is a partially schematic side view of a gas-liquid mixer 50 including an alkane injection system 40 in accordance with an embodiment of the present



invention. The alkane injection system 40 includes an alkane cylinder 42 and an inert gas cylinder 44 which may contain a gas such as helium. A regulator 46 is connected between the alkane cylinder 42 and the inert gas cylinder 44. An alkane injection line 48 connects the alkane injection system 40 to the mixer 50. The mixer 50 includes a wastewater containment vessel 51. A draft tube 52 and an impeller 53 are positioned in the wastewater containment vessel 51. A conical inlet baffle 54 is located at the top of the draft tube 52, while an outlet baffle 55 is located at the bottom of the draft tube 52. An air injection line 58 extends into the draft tube 52 below the conical inlet baffle 54. During operation of the system shown in Fig. 5, rotation of the impeller 53 draws wastewater vertically downward through the draft tube 52. Alkanes delivered through the injection line 48 and air delivered through the air injection line 58 mix with the wastewater inside the draft tube 52.

**[0039]** Fig. 6 is a partially schematic side view and Fig. 7 is a top view of a gas-liquid mixer including an alkane injection system 40 in accordance with another embodiment of the present invention. The alkane injection system 40 shown in Figs. 6 and 7 is similar to the system shown in Fig. 5. In the embodiment shown in Figs. 6 and 7, the gas-liquid mixer 60 includes a wastewater containment vessel 61 having a draft tube 62 with an impeller 63 mounted therein. An inlet baffle 64 is mounted at the top of the draft tube 62, while an outlet baffle 65 is mounted at the bottom of the draft tube 62. During operation of the mixer 60 shown in Figs. 6 and 7, rotation of the impeller 63 draws the wastewater through the draft tube 62, and also causes air-filled vortices to form, thereby entraining air as the wastewater is drawn through the draft tube 62. Alkanes fed through the alkane injection lines 48 are also entrained in the wastewater as it is drawn through the draft tube 62.

**[0040]** Fig. 8a is a schematic diagram illustrating a butane-enhanced wastewater treatment process in accordance with an embodiment of the present invention. In the embodiment shown in Fig. 8a, butane-enhanced odor control is achieved by introducing butane into the wastewater prior to the primary settling tank. After the primary settling tank, the wastewater may flow to a butane-enhanced aeration tank, then to a belt filter press. In addition, wastewater from the primary settling tank may be fed to a butane-enhanced aeration tank for secondary treatment. In the secondary treatment stage, return

activated sludge is fed to the butane-aeration tank and then to a final settling tank. After the final settling tank, the wastewater may be fed to a chlorine contact tank and/or another butane-enhanced aeration tank. The embodiment shown in Fig. 8b is similar to the embodiment shown in Fig. 8a, except the secondary treatment stage includes a standard aeration tank, rather than a butane-enhanced aeration tank.

**[0041]** Fig. 9 is a schematic diagram illustrating a butane-enhanced wastewater treatment process in accordance with another embodiment of the present invention. In the embodiment shown in Fig. 9, wastewater undergoes butane-enhanced odor control before it is fed to a primary settling tank. A secondary treatment stage similar to that shown in Fig. 8b is used, except the final settling tank is connected to a gravity thickener. Wastewater exiting the gravity thickener is fed to an anaerobic digester, followed by a butane-enhanced aeration tank. After treatment in the butane-enhanced aeration tank, the wastewater is fed to a belt filter press. Some of the material from the gravity thickener, anaerobic digester, butane-enhanced aeration tank and belt filter press may be recycled to the primary settling tank.

**[0042]** The butane injection processes may be used to treat BOD, TOC, ammonia, nitrates, nitrites, phosphorus, total organic carbon, organic and mineral settleable and nonsettleable suspended solids, organic and mineral colloidal and dissolved filterable solids and sludge. For example, the butane/air process will treat sludge and solids contaminated with nitrogen-based aromatics (explosives), PCBs, pesticides, chlorinated aliphatic and aromatic compounds, aliphatic and aromatic hydrocarbons, and PAHs, esters, ethers, aldehydes, amines, dioxin-and related compounds, herbicides, ketones, phenols, sulfur-containing organics and alcohols, ethylene dibromide (EDB), chlorophenolic compounds (chlorophenols, chloroguaiacols, and chlorocatechols, pulp mill effluent, low-level radioactive wastes, chlorate (pulp bleaching), cyanide, arsenic, chromium, copper, iron, lead, and other metals.

**[0043]** Some of the pollutants which may be degraded by the present system and method include chlorinated aliphatics, chlorinated aromatics and non-chlorinated aromatics and aliphatics, with chlorinated aliphatic hydrocarbons being of particular interest. Specific hydrocarbon pollutants include trichloroethene (TCE), trichloroethane (TCA) (e.g., 1,1,2-trichloroethane and 1,1,1-trichloroethane), methylene chloride, 1,1-

dichloroethane, chloroform, 1,2-dichloropropane, dibromochloromethane, 2-chloroethylvinyl ether, tetrachloroethene (PCE), chlorobenzene, 1,2-dichloroethane, bromodichloromethane, trans-1,3-dichloropropene, cis-1,3-dichloropropene, bromoform, chloromethane, bromomethane, vinyl chloride, chloroethane, 1,1-dichloroethene, trans-1,2-dichloroethene, methyl tertiary butyl ether (MTBE), polychlorinated biphenyl (PCB), dichlorobenzenes, cis-1,2-dichloroethene, dibromomethane, 1,4-dichlorobutane, 1,2,3-trichloropropane, bromochloromethane, 2,2-dichloropropane, 1,2-dibromoethane, 1,3-dichloropropane, bromobenzene, chlorotoluenes, trichlorobenzenes, trimethylbenzenes, trans-1,4-dichloro-2-butene and butylbenzenes. Additional pollutants include petroleum compounds such as crude oil, refined oil, Nos. 2, 4 and 6 fuel oils, gasoline, benzene, toluene, ethylbenzene and xylene (BTEX), and creosote.

**[0044]** Facultative anaerobes and microaerophilic bacteria are capable of surviving at low levels of oxygen. They do not require strict anaerobic conditions such as the obligate anaerobes. Acidophilic, alkaliphilic, anaerobe, anoxygenic, autotrophic, chemolithotrophic, chemoorganotroph, chemotroph, halophilic, methanogenic, neutrophilic, phototroph, saprophytic, thermoacidophilic, and thermophilic bacteria may be used.

**[0045]** Wastewater treatment processes that may be used in accordance with the present invention include the use of butane-utilizing microorganisms which may be found naturally in wastewater. Bacteria may include the following Groups (in addition to fungi, algae, protozoa, rotifers and all other microbial populations found in municipal, agricultural and industrial wastewaters.)

- Group 1: The Spirochetes
- Group 2: Aerobic/Microaerophilic, motile, helical/vibroid, gram-negative bacteria
- Group 3: Nonmotile (or rarely motile), gram-negative bacteria
- Group 4: Gram-negative aerobic/microaerophilic rods and cocci
- Group 5: Facultatively anaerobic gram-negative rods
- Group 6: Gram-negative, anaerobic, straight, curved, and helical bacteria
- Group 7: Dissimilatory sulfate- or sulfur-reducing bacteria

- Group 8: Anaerobic gram-negative cocci
- Group 9: Anoxygenic phototrophic bacteria
- Group 10: Oxygenic phototrophic bacteria
- Group 11: Aerobic chemolithotrophic bacteria and associated organisms
- Group 12: Budding and/or appendaged bacteria
- Group 13: Sheathed bacteria
- Group 14: Nonphotosynthetic, nonfruiting gliding bacteria
- Group 15: The fruiting, gliding bacteria and the Myxobacteria
- Group 16: Gram-positive cocci
- Group 17: Endospore-forming gram-positive rods and cocci
- Group 18: Regular, nonsporing, gram-positive rods
- Group 19: Irregular, nonsporing, gram-positive rods
- Group 20: The mycobacteria
- Groups 21-28: The actinomycetes
  - Group 21: Nocardioform actinomycetes
  - Group 22: Genera with multiocular sporangia
  - Group 23: Actinoplanetes
  - Group 24: Streptomyces and related genera
  - Group 25: Maduromycetes
  - Group 26: Thermomonospora and related genera
  - Group 27: Thermoactinomycetes
  - Group 28: Genus Glycomyces, Genus Kitasatospira and Genus Saccharothrix
- Group 29: The Mycoplasmas – cell wall-less bacteria
- Group 30: The Methanogens
- Group 31: Archaeal sulfate reducers
- Group 32: Extremely halophilic, archaeobacteria (halobacteria)
- Group 33: Cell wall-less archaeobacteria
- Group 34: Extremely thermophilic and hyperthermophilic S<sup>0</sup>-metabolizers

**[0046]** Degradation of complex organic pollutants in the butane digester preferably requires the interaction of microbial populations (consortia). Butane or alkane-utilizing bacteria may degrade pollutants aerobically (or anaerobically) through direct metabolism, sequential metabolism, reductive metabolism, dehalogenation, or cometabolism.

**[0047]** The requirement for a controlled environment and biological community may dictate the design of treatment facilities and the kinetics of biological growth. Typically, during conventional wastewater treatment, bacterial growth can be expressed as the variation of the mass of the microorganisms with time. Four phases have been used to describe bacterial growth: the lag phase; the log-growth phase; the declining growth phase; and the endogenous phase.

**[0048]** The lag phase represents the time required for bacteria to acclimate to their nutritional environment. Butane availability may shorten the lag phase by acclimating (and stabilizing) the microbial populations in their environment. For example, by stabilizing the microbial populations during pulsed cycles of butane and air (or oxygen), the entire microbial community may be better adapted for purification processes.

**[0049]** In the log-growth phase, there is excess food surrounding the organisms, and the rate of metabolism and growth is a function of the ability of the bacterial populations to process the substrate. Because of its solubility, pulsed cycles of butane may adapt the microbial populations to better utilize the excess of available carbon substrates (of varying availabilities) in the wastewater by acclimating (and stabilizing) the microbial populations in the apparently nutrient-rich environment. This in turn will increase the microbial communities to process an increased number of available substrates. Butane may be pulsed to create feeding frenzy/starvation cycles. During the starvation cycle, the increased microbial populations (a larger percentage of the population containing butane-utilizing bacteria) will be forced to consume and mineralize the remaining wastewater constituents, such as organic substrates possessing varying microbial availabilities at biological rates that would exceed conventional treatment processes.

**[0050]** In the declining growth phase, the rate of increase of bacterial mass decreases because of limitations in the food supply. Butane availability will reverse the

effects of limitations in the food supply thereby increasing the rate of bacterial mass. During conventional wastewater treatment, the established microbial populations consume the most readily available carbon sources. As the readily available sources diminish, the more recalcitrant carbon sources remain in the wastewater mix. This in turn causes a decrease in the bacterial mass. Butane pulsing offsets the effects of carbon source availability by reinforcing and strengthening the adapted microbial populations. The adapted populations attack the remaining carbon sources during the starvation cycles with renewed vigor.

[0051] In the endogenous phase, microorganisms are forced to metabolize their own protoplasm without replacement because the concentration of available food is at a minimum. Butane availability will reverse the effects of the endogenous phase. With butane pulses, the endogenous phase period will be drastically reduced and may occur (if at all) during the starvation cycles (of short duration).

#### EXAMPLE

[0052] Return activated-sludge (RAS) was collected from a municipal wastewater treatment plant located in Massachusetts. The RAS was drawn from the return line of a settling tank (after treatment in an aeration tank) in an activated-sludge process municipal wastewater treatment plant. RAS consists of the mixture of old and new aerobic bacterial cells, which have settled out in the settling tank over a period of time. The activated-sludge was introduced into a bioreactor vessel comprising aeration diffusers, a constant speed electric mixer with propeller, an air-supply pump, and vent line, as illustrated in Fig. 10. The bioreactor 70 shown in Fig. 10 includes a containment vessel 71 with a screw down cover 72 sealed with a gasket 73. A vent line 74 extends through the cover 72. An impeller 75 mounted in the vessel 71 is rotated by a motor assembly 76. An air supply pump 80 is connected to an air feed line 81. A butane injection port 82 is connected to the air feed line 81. A diffuser 84 is connected at the end of the air feed line 81.

[0053] The reactor contained approximately five gallons of organic waste, which consisted of water with the addition of the return activated-sludge from the treatment plant. The return activated-sludge appeared to have the consistency of slurry prior to the

addition of water. Prior to the butane injections, the solids were thoroughly mixed and a composite sample was drawn for analysis of total solids. The results are summarized in Table 1 below. The constant speed mixer and aeration system were operated continually (200 liters per hour) with brief stops every hour to conduct butane injections (500 ml of n-butane). The butane was injected into a syringe port connected to the air-supply line at hourly intervals as shown on Table 1 and in Fig. 10. After a period of approximately three days, the butane injections were halted. During the hours not shown in the table, the bioreactor was operated with aeration and mixing without butane injection.

Table 1

Day No.	Time	Volume of Butane	Aeration (200 L/hr)	Mixing
1	19:00	500 ml	On	On
1	20:00	500 ml	On	On
1	21:00	500 ml	On	On
2	08:00	500 ml	On	On
2	09:00	500 ml	On	On
2	11:00	500 ml	On	On
2	12:00	500 ml	On	On
2	13:00	500 ml	On	On
2	14:00	500 ml	On	On
2	15:00	500 ml	On	On
2	16:00	500 ml	On	On
2	17:00	500 ml	On	On
2	18:00	500 ml	On	On
2	19:00	500 ml	On	On
2	20:00	500 ml	On	On
3	10:00	500 ml	On	On
3	11:00	500 ml	On	On
3	12:00	500 ml	On	On
3	13:00	500 ml	On	On
3	14:00	500 ml	On	On
3	15:00	500 ml	On	On
3	16:00	500 ml	On	On
3	17:00	500 ml	On	On
3	18:00	500 ml	On	On

**[0054]** On Day No. 1, a pretreatment composite sample was collected from the bioreactor after thorough mixing of the RAS with the propeller unit (2 minutes). The

sample was submitted to Rhode Island Analytical Laboratory for total solids analysis referencing EPA Method 160.3. The results are summarized in Table 2 below.

Table 2

Day No.	Total Solids (mg/l)	Settleable Solids (ml/l)
1 (Pretreatment)	2,200	329
5 (Butane Treatment)	1,900 (14% reduction)	158 (52% reduction)

[0055] On Day No. 5, a composite sample was collected from the bioreactor (post butane treatment) and submitted to Rhode Island Analytical Laboratory for total solids analysis referencing EPA Methods 160.3. The results are summarized in Table 1.

[0056] The RAS slurry immediately thinned (within 10 hours) after the butane injections. The RAS appeared less dense with a flocculant consistency. In addition, all odors associated with the RAS sludge sample were not detectable by olfactory senses after the first three butane injections conducted on Day No. 1. Thus, butane may be used for odor control in wastewater and other industries.

[0057] On Day No. 3, the sludge was observed to rise in the bioreactor chamber and into the vent tubing. In addition, small diameter bubbles were observed at the liquid surface. We believe the bubbles were nitrogen gas generated during denitrification processes. As the nitrogen gas formed in the RAS, the sludge mass became buoyant and rose in the bioreactor chamber (rising sludge phenomenon). Since denitrification was believed to be an anaerobic process, this phenomenon was unexpected since the aeration process was operated continually during the process treatment. Although not intending to be bound by any particular theory, the principal biochemical pathways of denitrification may not be anaerobic but rather a modification of aerobic pathways. Alternatively, the butane injections may have increased oxygen demand to the point that exceeded the capacity of the aeration unit used for the study. Consequently, the bioreactor may have turned slightly anoxic. The bioreactor example described above only details the process and method conception. Optimization of the process (i.e., butane volume and flow rates) was not detailed or considered.



**[0058]** In accordance with an embodiment of the present invention, butane enhanced treatment of wastewater may be conducted as a modification of existing aeration tanks in municipal or chemical wastewater treatment facilities or as stand alone or ancillary treatment reactors. Many variations or process permutations exist or may be implemented using the alkane process. The process could be modified to pre-treat sludge, treat sludge on-line, treat return sludge, lower biological oxygen demand, total organic carbon or any other form of wastewater where solids reduction, odor control or organics removal is desirable. The alkane process may also be used to further treat sludge obtained from anaerobic digestion processes. The process may be used to reduce solids in any type of wastewater effluent. Furthermore, butane may be injected into wastewater early in the treatment process to abate nuisance odors associated with wastewater liquids/solids.

**[0059]** Whereas particular embodiments of this invention have been described above for purposes of illustration, it will be evident to those skilled in the art that numerous variations of the details of the present invention may be made without departing from the invention as defined in the appended claims.